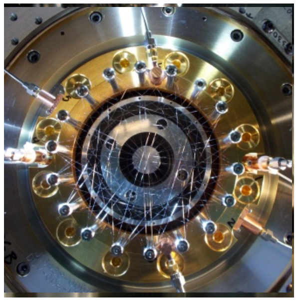

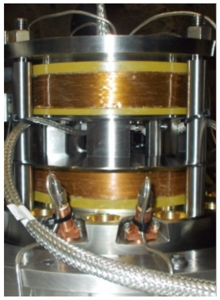

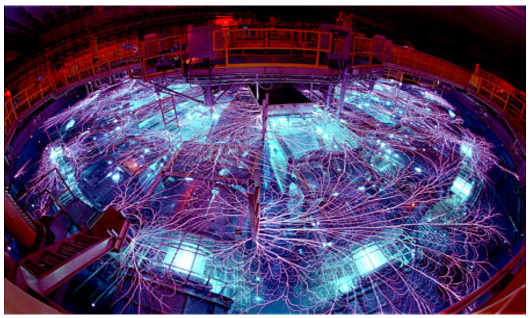

Sandia National Laboratories

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Neutron/Gamma 4 Outbrief

Spears/Kilkenny	LLNL	Antipodal nTOFs
Grim	LLNL	Precision nTOF
Beeman/Moore	LLNL	High DR electrical recording
Rinderknecht	MIT	Diag. signatures of kinetic effects
Murphy	LANL	DD/DT ion temperatures
Gatu-Johnson	MIT	DD/DT ion temperatures
Knauer	LLE	nTOFs on NIF and Omega
Danly	LANL	Spatially-resolved Tion

Session chair: Brent Jones
Manager Org. 1677
Neutron and Particle Diagnostics
Sandia National Laboratories
bmjones@sandia.gov

National Diagnostics Workshop
Los Alamos, NM
October 6-8, 2015

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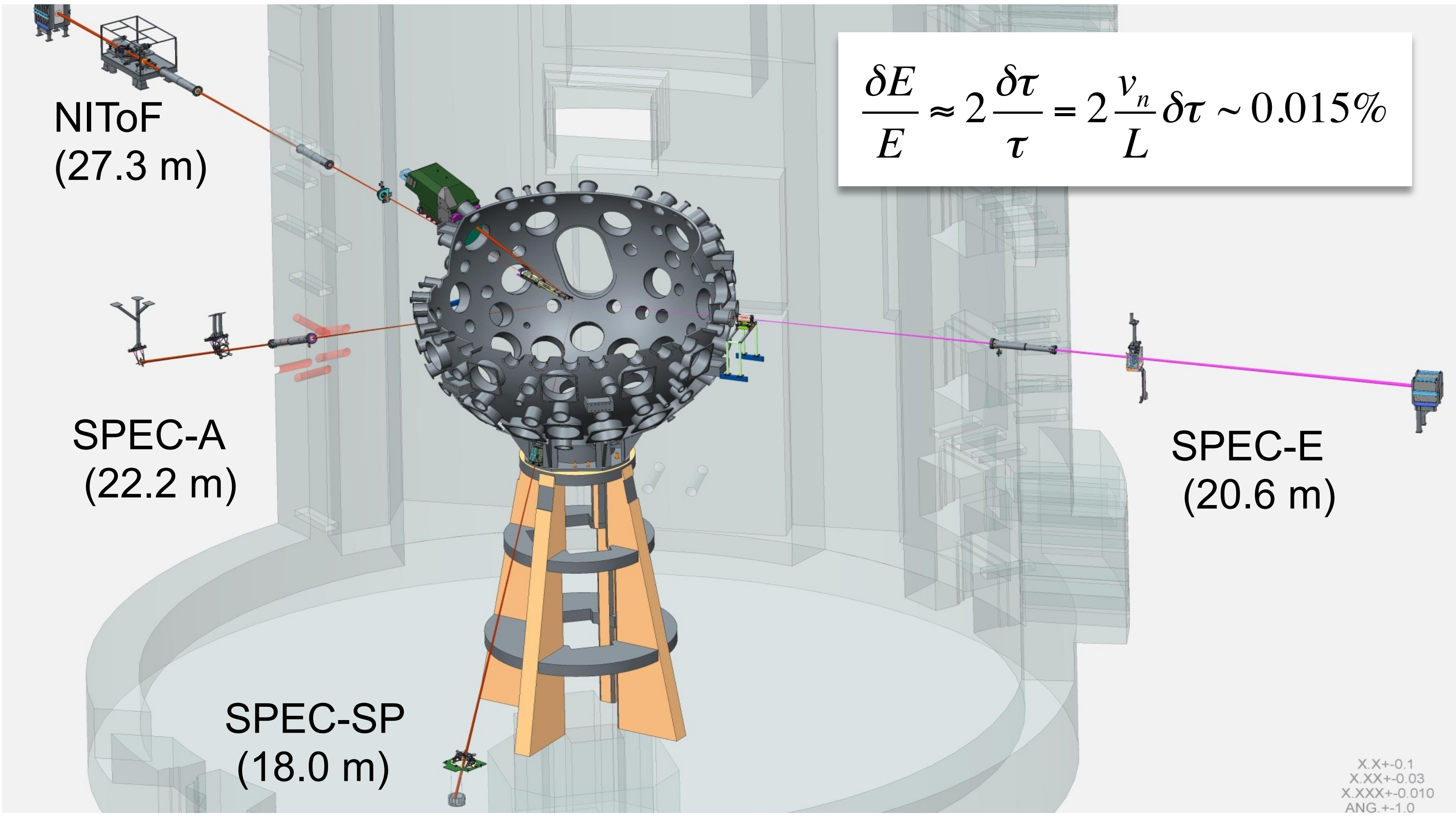
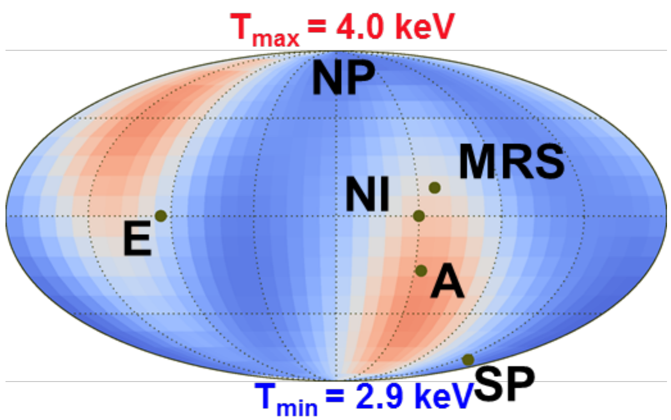
What would we gain by adding another nTOF detector to the NIF suite? Consider North pole versus near equatorial…



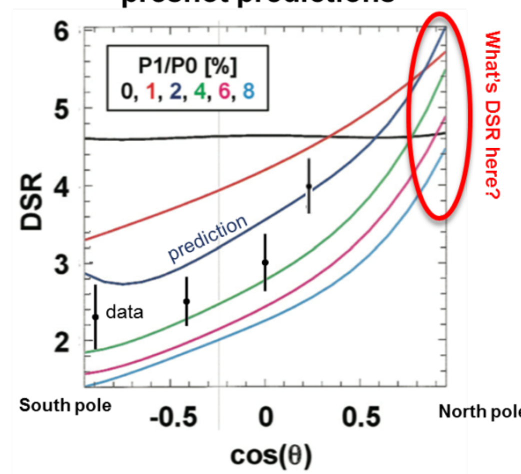
$$\frac{\delta E}{E} \approx 2\frac{\delta\tau}{\tau} = 2\frac{v_n}{L}\delta\tau \sim 0.015\%$$

Spears

Adding an antipodal nTOF at NIF improves resolution of T_{ion} and may inform understanding of bulk flows



Experiments compare nicely with preshot predictions



- Is the high foot apparent T_{ion} usually isotropic or not?
  - Antipodal nTOFs provide measure of bulk flows and constrain thermal T_{ion}
  - Expect same apparent T_{ion} on opposing sides
  - Simulations suggest apparent T_{ion} anisotropy of 300-400 keV
  - Present detectors can resolve 500 keV anisotropy, require 100 keV res.
- North pole nTOF measures odd mode in cold shells

Spears

Analysis of neutron spectral moments can provide physical insight into flows and be used to test models

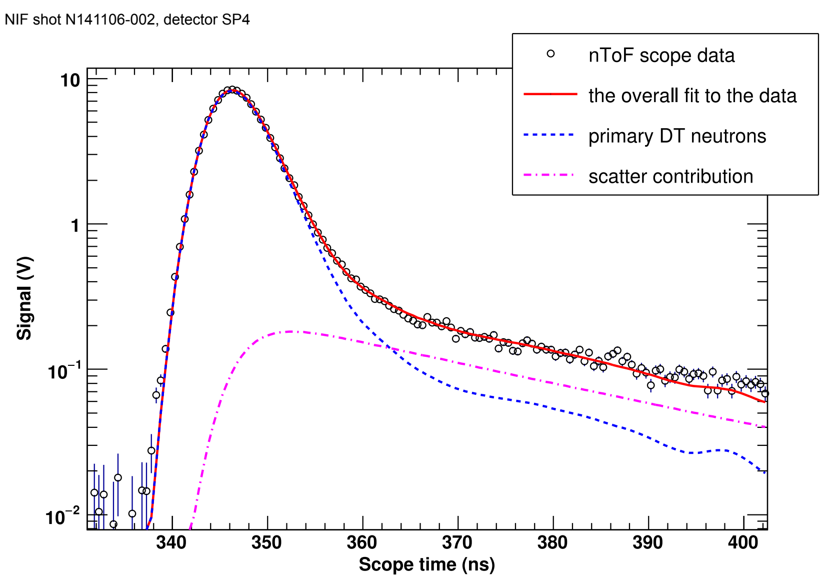
- **Moments:** **1st:** peak shift, gives bulk flow velocity
  2nd: width, apparent ion temperature
  3rd: skew, is hot stuff moving fast?
  4th: kurtosis, distribution of thermal temperatures

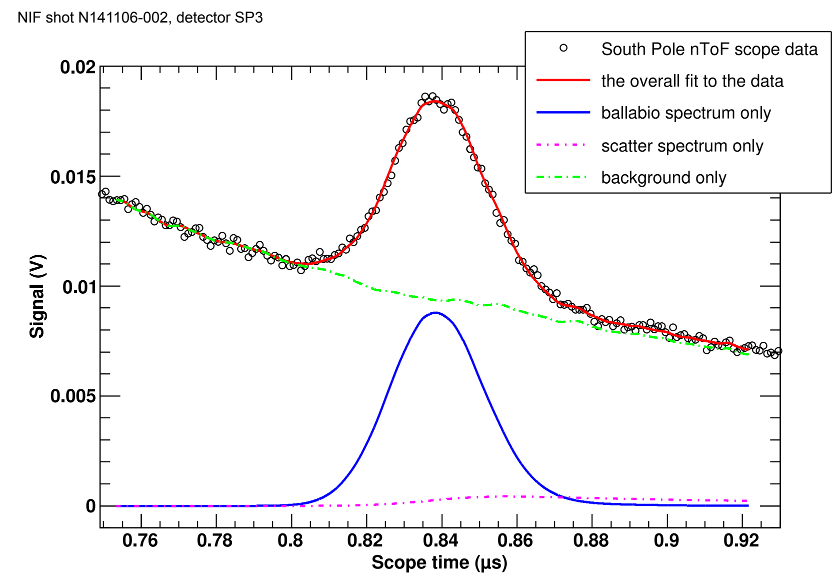
- **Sangster:** What about other targets? Vacuum hohlraum? Rugby?
- **Petrasso:** What about exploding pushers? These are very hydrodynamic and should have no flows…
- **Kilkenny:** …except radial.
- **Spears:** Yes, it would be good to consider other geometries.
- **Frenje:** You are considering stationary flows. How does time-dependence of v, T_{ion} affect interpretation?

nTOF neutron spectra being generated and measured on NIF today are unprecedented and exciting

$Y_{unsc} = 2.8 \pm 0.04 \times 10^{15}$
$V_{DT} = 39.3 \pm 15$ km/s
$T_{ion} = 4.43 \pm 0.14$ keV

$Y_{unsc} = 1.02 \pm 0.09 \times 10^{13}$
$V_{DT} = 40 \pm 15$ km/s
$T_{ion} = 4.04 \pm 0.17$ keV

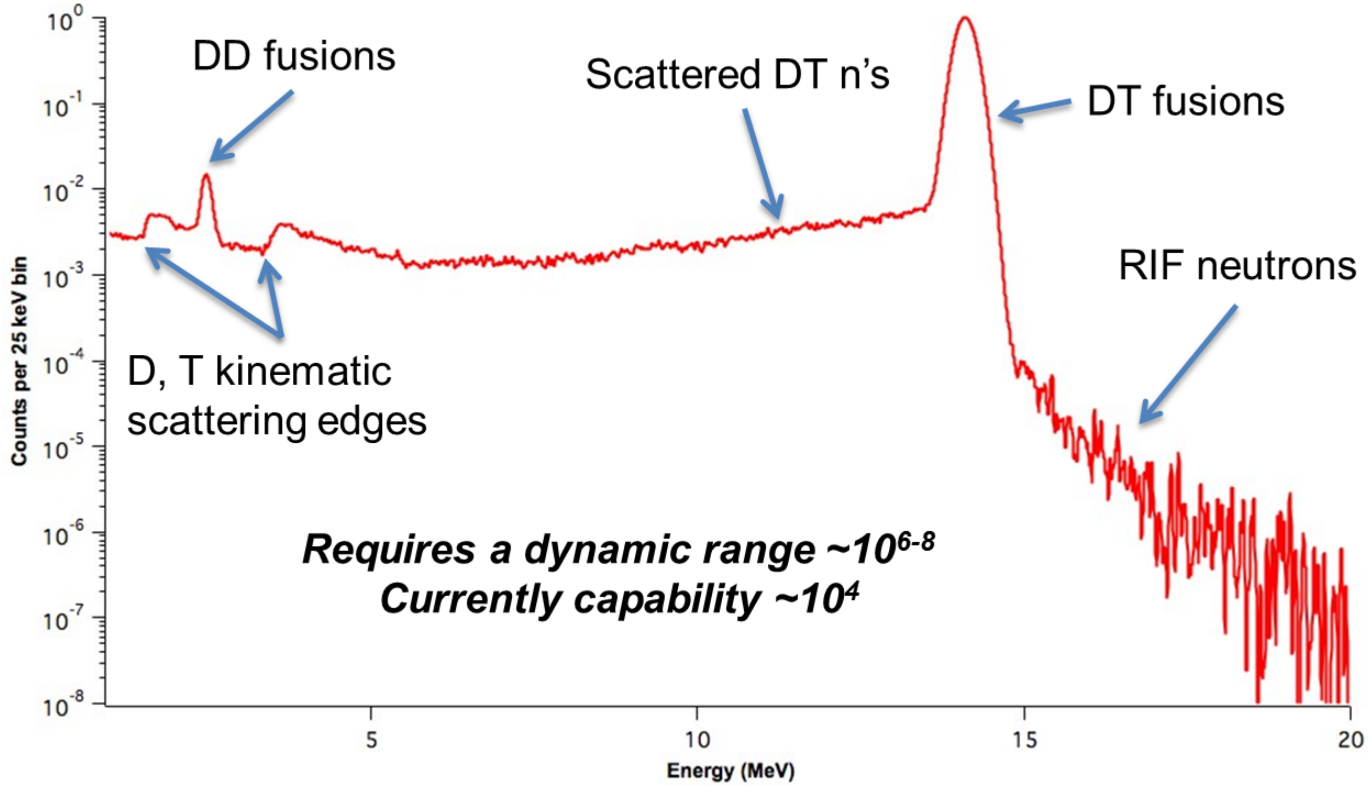


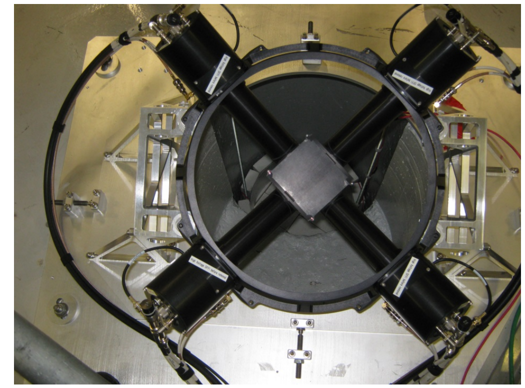


- Current NIF nToF systems report the 0th - 2nd moments spanning a dynamic range of ~300.
- DT and DD peak moments are measured with % level accuracy.

Grim

"Precision nTOF" aims to measure neutron spectrum on NIF over many orders of magnitude dynamic range e.g. to capture RIFs





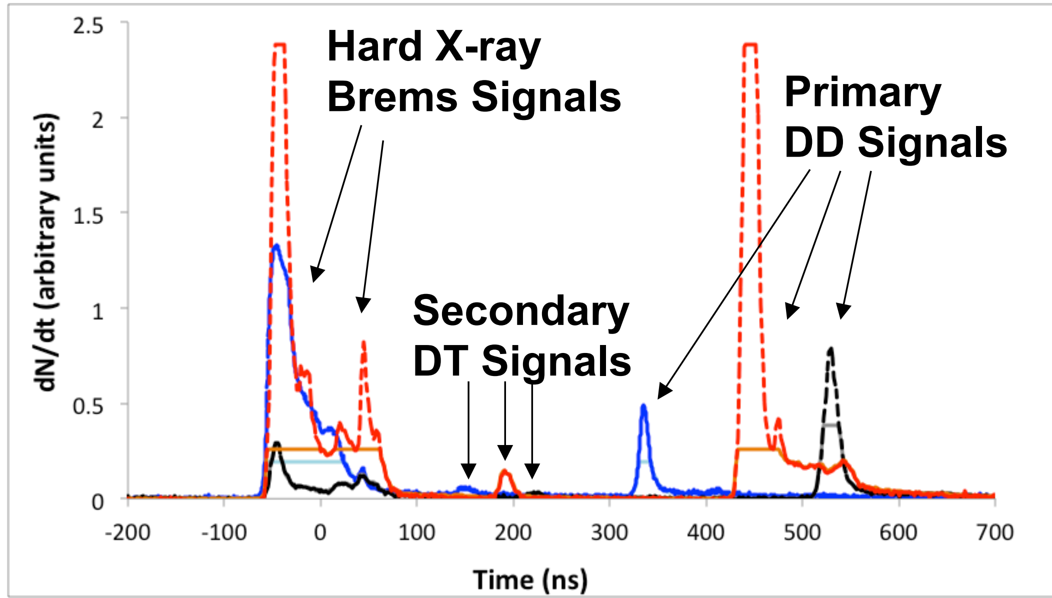
NTOF Spec SP:
Four tubes looking at the same bibenzyl scintillator. Flexibility to measure many different quantities on a single shot (DD, DT, TT, RIF neutrons - customizable)

- One goal is to improve systematic uncertainties
  - New detector systems with improved characteristics
  - Higher sensitivity digital recording

Moment	Precision
1st	0.02%
2nd	100 eV
3rd	0.3%
4th	1%

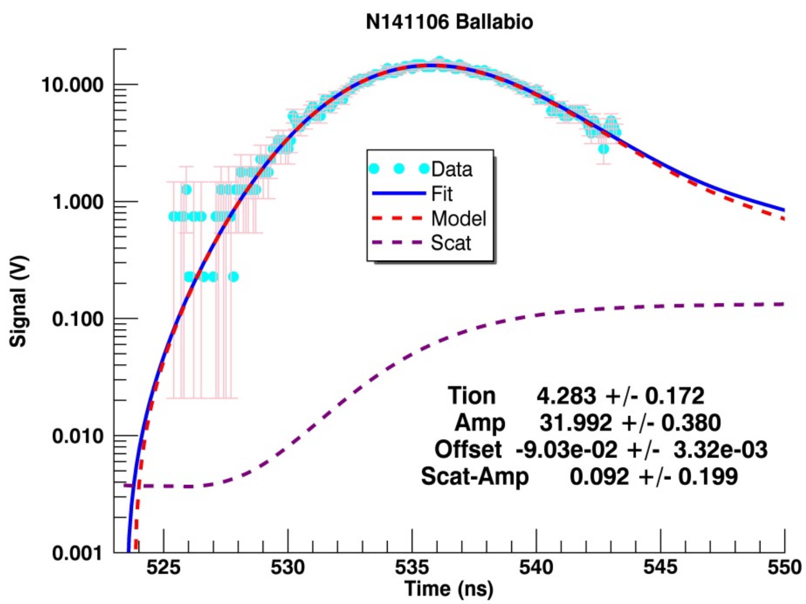
What does nTOF improvement on Z look like?

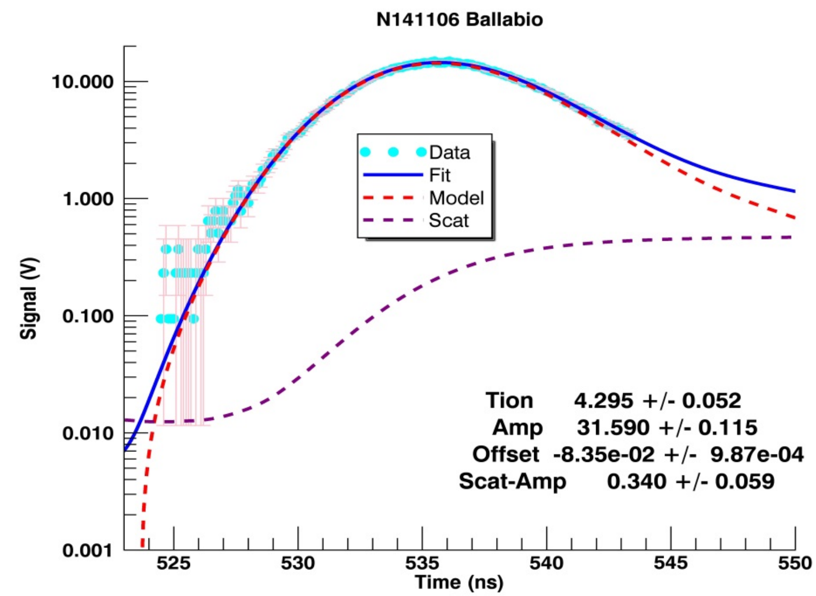
- NIF has unique challenges due to DT high yields
  - **Kilkenny:** Is 1-2 nC good enough? When are we worried about saturation?
- Z may get there eventually, challenge is now the small secondary DT yields
- Next year, focus on quality of DT spectrum on Z
  - Gated PMTs, NRPU, fast scintillators, shielding to mitigate brems pulse
  - ICF diag. meeting has helped to initiate collaborations



Key Collaborations on nTOF		
NSTec R. Buckles I. Garza K. Moy	**LLE** V. Glebov	**LLNL** D. Fittinghoff M. May
Gated PMTs, fast scintillators, close-in nTOF, clipper circuits, CVD diamonds		

Digital recording ENoB plays a significant role in moment analysis

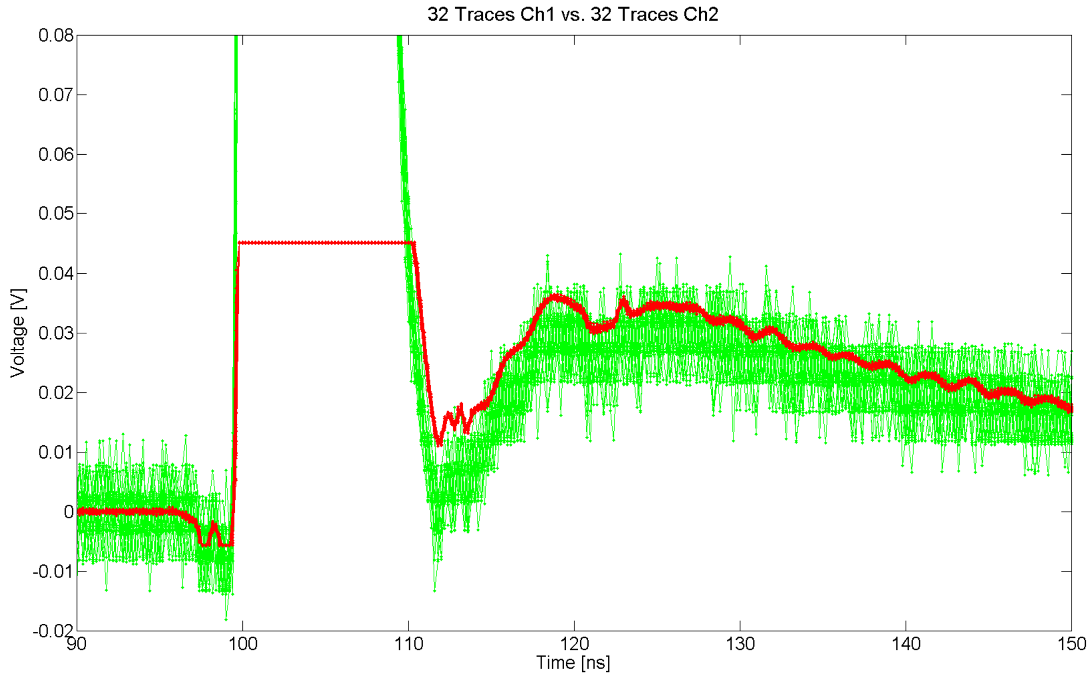




- A factor of 4 increase in Effective Number of Bits reduces fits uncertainties by 3x and dramatically improves the significance of the fit to the scattered flux
- Increased ENoB also improves fit sensitivity to higher moments…

Moore

Stitching split signals together can enhance dynamic range, but beware of overdriving scopes



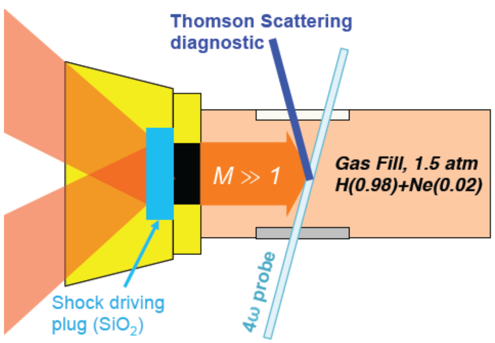
- Digital scopes are fast and cost effective
  - **Knauer:** What about 11-bit CAMAC?
- Can take ~20 ns to recover after overdrive
- DSP can affect more of record

- Large overdrive ratio: 10ns, 125mV/div and 5mV/div, ~1V pulse, 25x overdrive
- Non-reflective protective unit (NRPU) work by NSTec looks promising in initial Z prototype—collaboration?

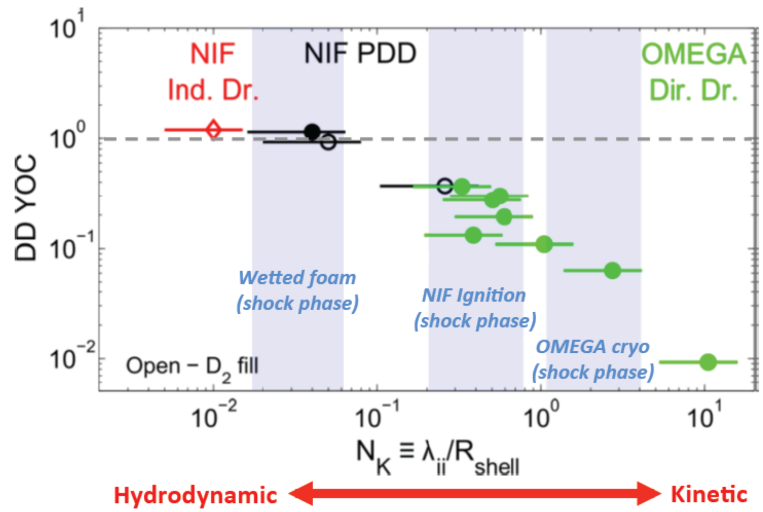
Rinderknecht

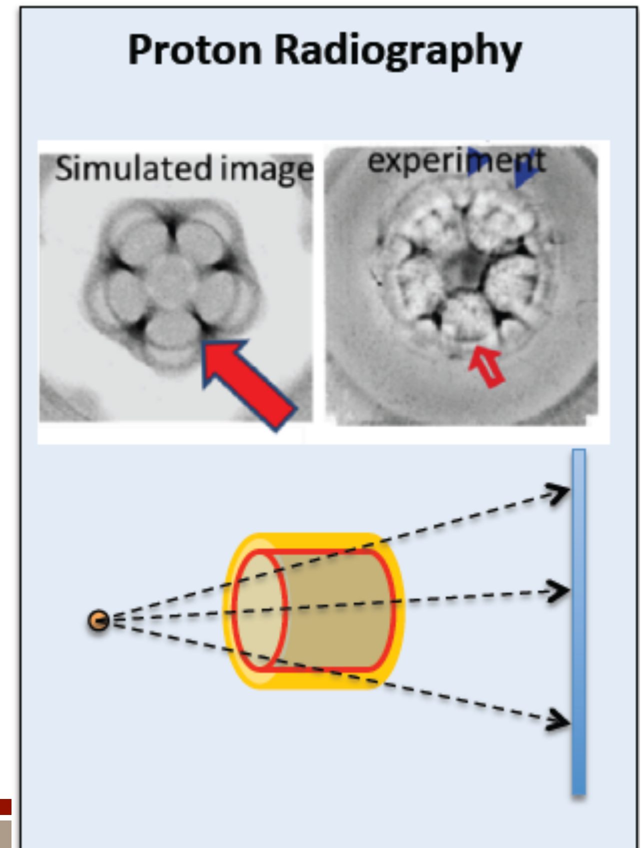
Kinetic effects can impact YOC and other more subtle observables

- Fusion product spectra are narrowed and shifted by tail-ion loss in the presence of Knudsen layers
- Thomson scattering is sensitive to ion concentration/diffusion
- Proton radiography can detect distinctive electric field structures



*similar to OMEGAJet-14A





- Experiments:
  - Omega shots, look for charge separation in planar shocks with H+Ne plasmas
  - Repeat capsules with larger NK but add B field to mitigate tail-ion losses

Murphy

Due to the ion mass difference, we expect different apparent T_{ion} from DD or DT spectra in the presence of bulk flows

Convolving the contributions of thermal CM and fluid CM, we can show:

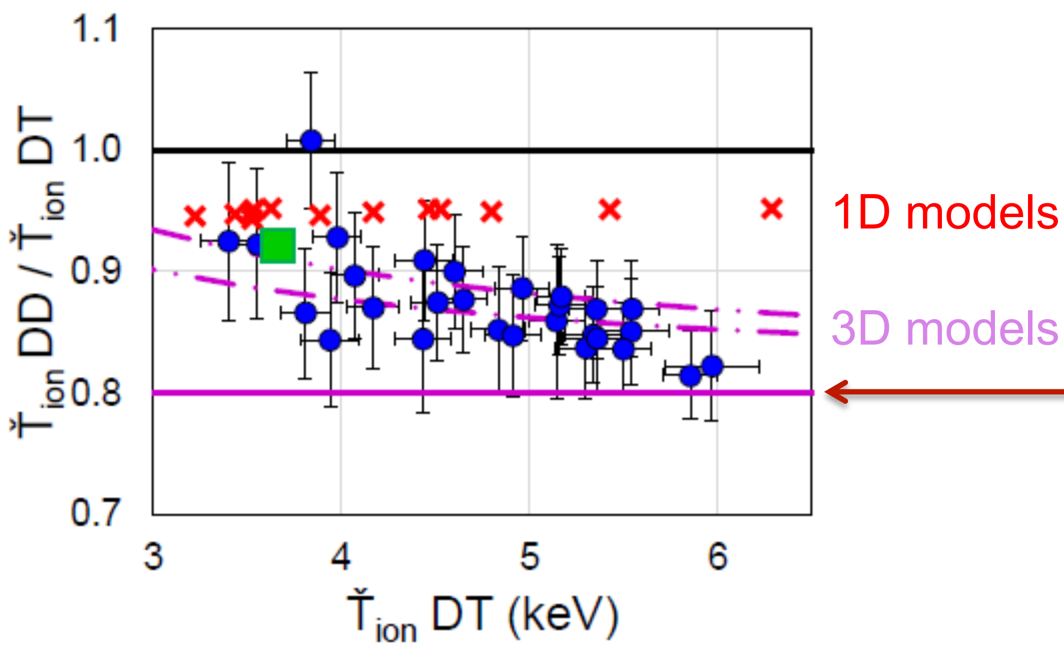
$$\begin{aligned}\sigma_n^2 &= \sigma_{n,th}^2 + \sigma_{n,f}^2 \\ &= 2m_n E' \frac{kT}{M} + 2m_n E_n' \sigma_{v,f}^2 \\ &= 2m_n E' \left(\frac{kT}{M} + \sigma_{v,f}^2 \right)\end{aligned}$$

$$\begin{aligned}kT_{app} &= \frac{M}{2m_n E_n'} \times 2m_n E' \left(\frac{kT}{M} + \sigma_{v,f}^2 \right) \\ &= kT + M\sigma_{v,f}^2\end{aligned}$$

- Ion temperature determination from neutron spectra usually assumes a stationary plasma
- Residual motion can significantly affect the inference of an ion temperature
- Comparison of DD and DT ion temperatures in DT plasmas can provide a measure of the fluid velocities

Gatu-Johnson

Trend in difference in apparent DD and DT T_{ion} is suggested to be due to 3D structure and residual flows



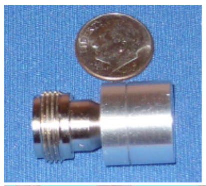
$$kT_{app} = \frac{M}{2m_n E_n'} \times 2m_n E' \left(\frac{kT}{M} + \sigma_{v,f}^2 \right)$$
$$= kT + M\sigma_{v,f}^2$$

$T_{DD} = 0.8\ T_{DT}$ for $T_{thermal} \rightarrow 0$

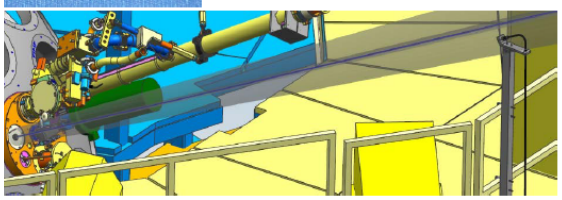
- Trend independent of ablator and hohlraum
- Variations in τ_{burn}, v_{imp}, r_{min}, ρr affect apparent Tion but not enough in 1D model to explain data
- Additional 3D modeling comparison to data will be valuable

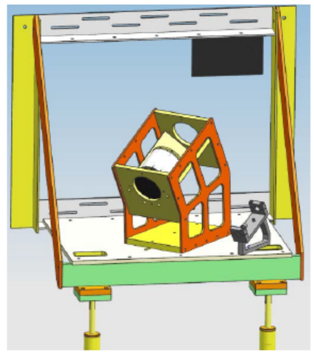
Knauer

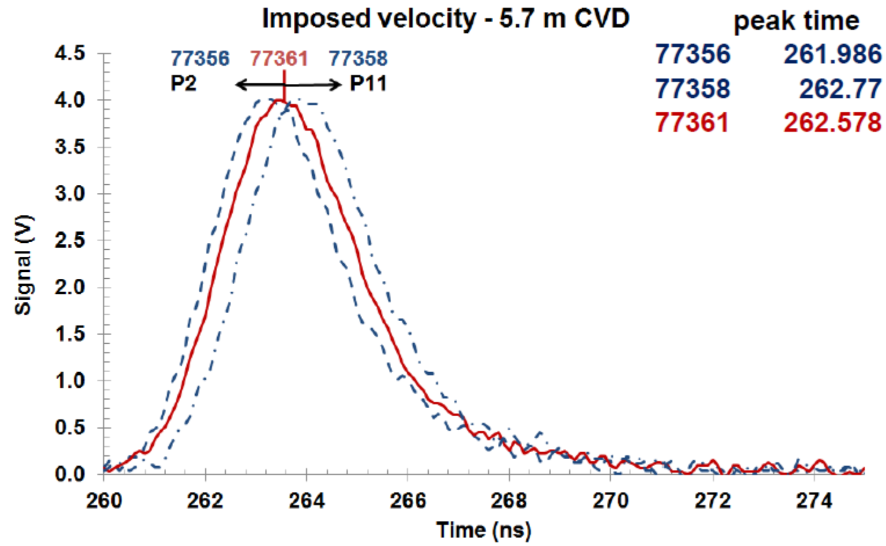
Plausibility of 3D bulk flow measurement has been demonstrated in single LOS on Omega



Two 10x1 mm CVD



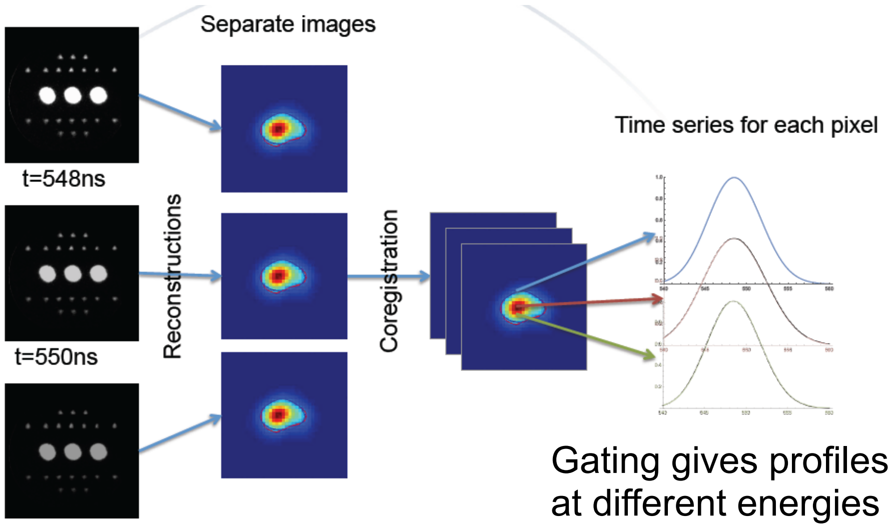


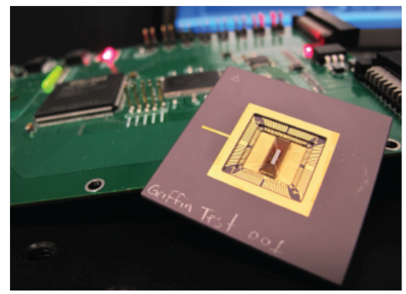


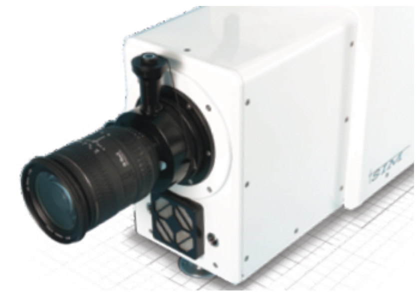
- CVD diamonds at 5.7 and 15.8 m show Doppler shifts with illumination perturbation (greater at 15.8 m)
- Net uncertainty ~17 km/s
- Next: implement 3 orthogonal measurements to measure 3D bulk flow velocity
- May be systematic error: CVD diamond IRF variation with dose

Danly

Enabled by higher yields, multi-frame neutron imaging could provide finer energy resolution and determination of T_{ion} profile at bang time







- Requires adding fast camera to existing NIF neutron imager, e.g. multi-frame, 1 GHz hybrid CMOS detector or other
- Reconstruction tradeoff between pixel size, energy resolution, statistical error
- e.g. at Y_{DT}=3e15, 10% error in T_{ion} at a 4 μm pixel on 17% contour
- Consider 1D imaging with slit (Fittinghoff) and streak camera

Continuing a focus on nTOF and diagnostics related to T_{ion} and fuel velocities will support stagnation physics insight

- **nTOF technologies discussed were perhaps not "transformative" but certainly are of "broad" interest to the HED facilities**
  - NIF has particular needs owing to high DT yield, e.g. tough nTOF dynamic range requirements and charge depletion concerns
  - All facilities NIF, Omega, Z share a common desire to understand T_{ion} and residual velocities at stagnation
  - Z has its own challenges, e.g. brems and low DT signals, but can benefit from technologies studied at Omega and NIF
  - Recommendation: keep nTOF and T_{ion}/velocity measurements within the scope of the national ICF/HED diagnostic discussion
- **Significant enthusiasm around complex physics that determines apparent T_{ion}, bulk flows, ion distribution**
- **Nuclear diagnostics provide valuable data linked to ion motion that complements x-ray data for physics and model validation**